Lower Extremity Injuries among Restrained Vehicle Occupants
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Introduction

Motor vehicle crashes are a major cause of lower extremity injuries. These injuries are costly, frequently result in lifetime impairments, and are preventable. Although current information in the biomechanics of these injuries is still insufficient, it is known that they occur most often in frontal and offset frontal collisions, that seatbelts may be ineffective with respect to their prevention, and that vehicular intrusions of the toepan and instrument panel have been implicated as possible causes (Proceedings, International Conference on Pelvic and Lower Extremity Injuries, 1995). Many collisions resulting in these injuries occur at delta v's well within the purview of current regulatory standards. It has been anticipated that with the increasing availability of airbags and resultant decrease in life-threatening head and thorax injuries, the relative importance of lower extremity injuries will increase.

Data from NHTSA's National Accident Sampling System (NASS) reveal that lower extremity injuries account for 32% of all AIS>2 injuries for belted occupants (24% for unbelted). Injuries to the ankle/foot complex account for 33% of the AIS>2 injuries for belted occupants (24% for unbelted), and are the most prevalent lower extremity injury (Morgan et al., 1991). Among patients admitted to trauma centers following motor vehicle crashes, approximately 20% of drivers had at least one lower extremity fracture; the highest incidence rate for a specific fracture is for ankle injuries, with an incidence rate of 5.7% (Dischinger et al., 1992). Surveys suggest that foot and ankle injuries account for 8-12% of all moderate-to-serious injuries sustained by motor vehicle occupants involved in frontal collisions (Otte et al.,, 1992; Crandall et al., 1994; Kruger at al., 1994). In a study of the one-year treatment charges for persons hospitalized in Maryland with motor vehicle-related injuries, lower extremity injuries accounted for 40% of the one-year motor vehicle trauma treatment charges in the state (MacKenzie et al., 1988).

Lower extremity injuries from car crashes tend to be high-energy injuries, which have a poorer prognosis than comparable low-energy injuries caused by slips and falls (States, 1986). Because they involve weight-bearing surfaces and joints, knee and ankle fractures often result in prolonged reductions in mobility. Proximal foot fractures (talus, calcaneus) involve the complex, weight-bearing joints of the ankle and hindfoot and may also result in long-term impairment and disability. However, the disabling nature of these injuries is not reflected by their low scores on injury severity scales, which are usually designed to reflect threat to life and not to predict nonfatal outcomes.

In a follow-up study of patients admitted to trauma centers, it was noted that, among individuals with moderate or severe injuries to the extremities, only 58% had returned to work at one year. (MacKenzie et al., 1988). Another study of functional outcomes after lower extremity fracture revealed that a significant proportion of patients hospitalized for treatment of a unilateral fracture of the lower extremity remain physically impaired at 6 months after discharge from the hospital. Most affected was the ankle joint; 55% of the patients had evidence of abnormal dorsi/plantar flexion (MacKenzie et al., 1993). At 12 months, one-half of the patients still reported minor to moderate disabilities. Six to 12-month improvements were noted for patients with both single and multiple metaphyseal or shaft fractures in one limb. Patients with foot fractures, however, showed no improvement. Measures of patient-oriented functional outcomes were worst for persons with three or more fractures to the same extremity and for fracture patterns typical of high energy forces (Mock et al., 1994).

With increasing survival rates among drivers in high-speed crashes, due to availability of both seatbelts and airbags, it is anticipated that there will be a relative increase in serious lower extremity injuries among people who would have previously died of multiple trauma, including head, thorax, abdominal, and lower extremity injuries (Burgess et al., 1995). From in-depth crash reconstruction studies, it is possible to learn more about the mechanism of these injuries, and thus, working with biomechanics experts, address scientific strategies for prevention (Bents, 1994).

The following tables describe the results of 37 in-depth studies of lower extremity injuries collected as part of the CIREN effort. The cases, which involved a total of 82 injuries, all met inclusion criteria and are based on patients from the Maryland, Michigan, and San Diego County centers.

Note: The methodology for the development of CIREN cases is discussed elsewhere.

Table 1
Summary of Crash Characteristics

Occupant	
Driver	89%
Passenger	11%
Restraint Use	
3-point belt	27%
2-point belt	5%
3-point belt + bag	41%
Bag only	27%
Point of Impact	
Frontal	82%
Lateral	18%
Collision Type	
2-car crash	59%
3+ car crash	11%
Fixed object	24%
Other	5%

A summary of the lower extremity injuries sustained by these 37 cases is shown in Table 2. It may be noted that more than two-thirds of the cases had multiple lower extremity fractures; in addition, the majority of these injuries occurred to the right, as opposed to the left, extremity.

Table 2
Distribution of Lower Extremity Fractures

Fracture	***N***
Pelvis	21
Femur	20
Patella	1
Tib/Fib	19
Ankle/Foot	21

Table 3 shows the distribution of injuries by fracture type and whether direct or indirect contact, or intrusion with contact were involved. It is apparent that the majority of pelvic and femur fractures were associated with combined contact and intrusion. For tibia/fibula and ankle fractures, on the other hand, many were contact only.

Table 3
Lower Extremity Fractures
and Related Contact/Intrusion
(NASS)

Fracture	***Direct Contact***	***Indirect Contact***	***Contact+ Intrusion***
Pelvis	2	1	18
Femur	4	4	12
Patella	1	0	0
Tib/Fib	8	0	11
Ankle/Foot	5	5	11

DISCUSSION

Not long ago, individuals involved in high speed crashes would have suffered serious multiple trauma to the head, chest, and abdomen, as well as their lower extremities (Siegel et al., 1993). Thus, these cases are, to some extent, ‘success stories’, since most of the cases are survivors. However, even with the protection afforded by seatbelts and airbags, it is apparent that patients admitted to trauma centers have still sustained serious lower extremity injury, necessitating treatment in a trauma center (Burgess et al., 1995; Loo et al., 1996).

The CIREN consortium represents a great opportunity to study the cause(s) of these injuries in greater detail. However, it is necessary to take a step beyond descriptive analyses, such as those presented here, and address more in-depth questions, such as the actual mechanism of injury, especially for the most disabling and costly of all lower extremity injuries, ankle and foot fractures. For such a collaborative effort to be successful, expertise in interpretation of orthopaedic injuries, may be shared by means of digital photographs, x-rays, and consultation with orthopaedic experts. Findings from previous research have revealed that: (1) not all foot and ankle injuries are associated with vehicular intrusion (Crandall, 1995), (2) axial load (often with associated inversion or eversion forces) plays a significant role in the causation of these injuries (Dischinger et al., 1994), and (3) driver anthropometry (Dischinger et al.,1995) and foot placement (Pilkey et al., 1994)are important factors. With the evolution of CIREN, it will be possible to address such questions at multiple centers, thus allowing for the collection of much larger numbers of cases.

Based on the real-world findings noted among patients admitted to trauma centers, CIREN engineering/biomechanics experts can try to replicate these injuries, using tools such as computer simulation or dummy crash test experiments. Moreover, engineers from the automotive industry can provide important insights into the dynamics of a crash from the perspective of vehicle standards and performance. Many lower extremity injuries are sustained in crashes with little or no intrusion. However, accident investigations, crash test data, and simulation results suggest that factors such as a vehicle’s change in velocity and rate and timing of intrusion must be considered when examining injury mechanisms of the lower extremities. Based on engineering input, CIREN data collection protocols may be tailored to obtain more detailed measurements, for example, of toepan intrusion.

In addition to the strengths afforded by medical expertise, CIREN has available sources of epidemiologic data, including NASS data as well as regional information available from police reports, hospital discharge records, and trauma registries. Such data provide the opportunity to determine the representativeness of the select cases studied by CIREN- e.g. how common are calcaneus fractures? Are they more common in drivers or passengers? occupants with or without seatbelts? Those in offset frontal vs. direct frontal collisions?, etc.

This multidisciplinary approach to the study of injuries due to motor vehicle crashes, is the major strength of CIREN. By combining in-depth injury and crash data, collected by experts in their own fields, new insights into the causation of lower extremity injuries can be gained.

REFERENCES

Proceedings, International Conference on Pelvic and Lower Extremity Injuries. Washington DC, December, 1995.

Morgan RM, Eppinger RH, and Hennessey BC. Ankle Joint Injury Mechanism for Adults in Frontal Automotive Impact, Proc 35th Stapp Car Crash Conf, SAE Paper No. 912902, 1991.

Dischinger PC, Cushing BM, Kerns TJ. Lower extremity fractures in motor vehicle collisions: Influence of direction of impact and seatbelt use. 38th Annual Proceedings, Association for the Advancement of Automotive Medicine, 1992, pp. 319-325.

Otte D, Rheinbaben H, Zwiipp H. Biomechanics of injuries to the foot and ankle joint of car drivers and improvements for an optimal car floor development. Proc 36th Stapp Car Crash Conference, SAE 922514, 1992.

Crandall JR, Klopp GS, Klisch S, Sieveka E, Pilkey W, Martin P. Research program to investigate lower extremity injuries. In-Depth Accident Investigations- Trauma Team Findings in Late Model Vehicle Collisions. Society of Automotive Engineers, SAE Paper No. 940711, 1994.

Kruger HJ, Heuser G, Kraemer B, Schmitz A. Foot loads and footwell intrusion in an offset frontal crash. Paper 94-S4-0-03. 14th ESV Conference, Berlin, Germany, 1994.

MacKenzie EJ, Shapiro S, Siegel JH. The economic impact of vehicular trauma: One year treatment related expenditures. 32nd Annual Proceedings, Association for the Advancement of Automotive Medicine, 1988: pp 53-68.

States, JD. Adult occupant injuries of the lower limb. In: Biomechanics and Medical Aspects of Lower Limb Injuries. Warrendale, PA: Society of Automotive Engineers, Inc.; 1986: pp97-107.

MacKenzie EJ, Siegel JH, Shapiro S, Moody M, Smith RT: Functional recovery and medical costs of trauma: an analysis by type and severity of injury. J Trauma 1988; 28:281-298.

MacKenzie EJ, Cushing BM, Jurkovich GJ, Morris JA, Burgess AR, deLateur BJ, McAndrew MP, and Swiontkowski MF. Physical impairment and functional outcomes six months after severe lower extremity fractures. J Trauma 34(4): 528-539, 1993.

Mock C, Jorkovich G, MacKenzie E, Swiontkowski M, Burgess A, Cushing B, deLateur B, McAndrew M, Morris J. Long-term functional outcome in trauma patients: assessment using the sickness impact profile (SIP). Proc 22nd Annual Mtg, American Public Health Association, p.158, 1994.

Burgess AR, Dischinger PC, O'Quinn TD, and Schmidhauser CB. Lower extremity injuries in drivers of airbag-equipped automobiles: Clinical and crash reconstruction correlations. Journal of Trauma 35(6):920-931, December 1993

Bents FD, Dischinger PC, and Siegel JH. Trauma center based crash investigation research: Methodologies and applications. SAE Paper No. 940709, 1994.

Siegel JH, Mason-Gonzalez S, Dischinger PC, Read KM, Cushing BM, Badellino MC, Goodarzi S, Smialek JE, Heatfield BM, Robinson RM, Parkinson K, Hill JH, Jackson JW, Livingston DJ, Bents FD, and Clark CC. Causes and costs of injuries in multiple trauma patients requiring extrication from motor vehicle crashes. Journal of Trauma 35(6): 920-931.

Siegel JH, Mason-Gonzalez S, Dischinger PC, Cushing BM, Read K, Robinson R, Smialek, J, Heatfield, B, Hill W, Bents F, Jackson J, Livingston D, and Clark CC. Safety belt restraints and compartment intrusions in frontal and lateral motor vehicle crashes: mechanisms of injuries, complications, and acute care costs. Journal of Trauma (5) 34: 736-759.

Loo GT, Siegel JH, Dischinger PC, Rixen D, Addis MD, O'Quinn TO, McCammon L, Schmidhauser CB, Marsh P, Hodge PA, Burgess AR, and Bents FR. Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. Journal of Trauma 41(6):935-951, December 1996.

Dischinger PC, Burgess AR, Cushing BM, et al. Lower extremity trauma in vehicular front-seat occupants: patients admitted to a Level I trauma center. In In-Depth Accident Investigation: Trauma Team Findings in Late Model Vehicle Collisions. Warrendale (PA) Society of Automotive Engineers, 1994, pp.11-18.

Dischinger PC, Burgess AR, Cushing BM, et al: Lower extremity trauma in vehicular front-seat occupants. In Proceedings of the 4th Annual Injury Prevention through Biomechanics Symposium, Detroit, Wayne State University, 1994, pp.29-42.

Crandall JR, Martin PG, Sieveka EM, Klopp GS, Kuhlmann TP, Pilkey WD, Dischinger PC, Burgess AR, O=Quinn TD, and Schmidhauser CB. The influence of footwell intrusion on lower extremity response and injury in frontal crashes. 39th Annual Proceedings, Association for the Advancement of Automotive Medicine, pp. 1-18, 1995.

Pilkey WD, Sieveka EM, Crandall JR, and Klopp G. The influence of foot placement and vehicular intrusion on occupant lower limb injury in full-frontal and frontal-offset crashes. Paper No. 94 S4 W31, presented at the International ESV Conference, 1994.

Dischinger PC, Kerns TJ, and Kufera JA. Lower extremity fractures in motor vehicle collisions: the role of driver gender and height. Accid Anal. And Prev. 27(4):601-606, 1995.